

6.4 MECHANICAL, ELECTRICAL, AND PLUMBING COMPONENTS

6.4.1 MECHANICAL EQUIPMENT

6.4.1.5 HVAC EQUIPMENT SUSPENDED IN-LINE WITH DUCTWORK

This in-line HVAC equipment typically includes suspended items of sheet metal construction such as fans, coils, VAV boxes, and blowers. The connection details for suspended equipment may also include vibration isolators. Current codes require bracing for all items weighing over 20 pounds that are mounted more than 4 feet above the floor.

TYPICAL CAUSES OF DAMAGE

- Poorly supported items can fall.
- Items can swing and impact structural, architectural or other mechanical items. Internal components may be damaged by shaking or impact.
- Connections of fuel lines, water piping, electrical conduit or ductwork may be damaged. Equipment may cease to function due to misalignment or internal damage.

Damage Examples



Figure 6.4.1.5-1 Damage to suspended HVAC, signs, and louvers was caused when suspended fans in the mechanical penthouse swung and impacted the louver panels. Holy Cross Medical Center in Sylmar, as a result of the 1994 magnitude-6.7 Northridge Earthquake (Photo courtesy of Robert Reitherman).

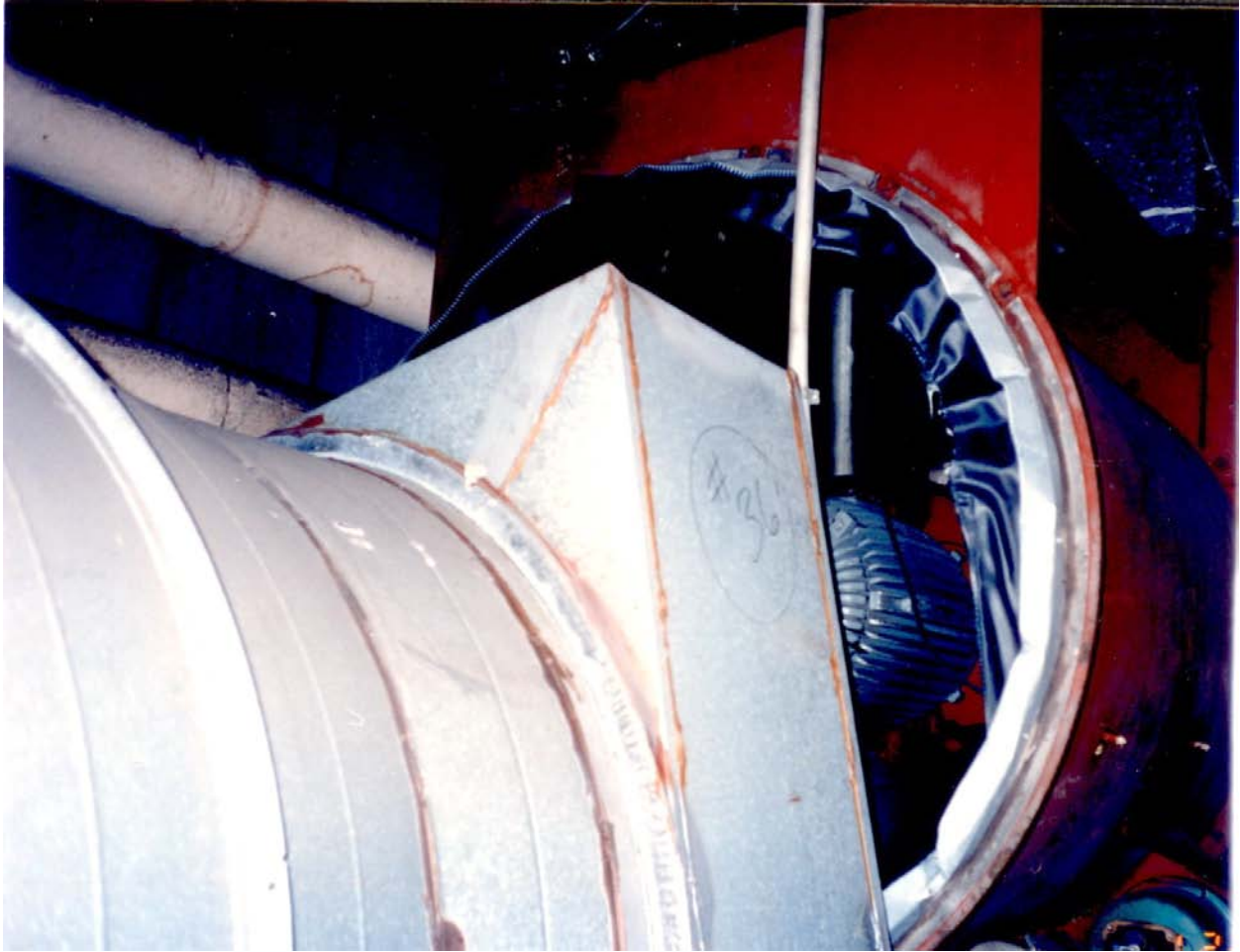


Figure 6.4.1.5-2 Sheet metal duct separated from suspended fan unit (Photo courtesy of Wiss, Jenney, Elstner Associates).



Figure 6.4.1.5-3 Suspended HVAC equipment came down at the Santiago airport terminal in the 2010 magnitude-8.8 Chile Earthquake (Photo courtesy of Gokhan Pekcan).

SEISMIC MITIGATION CONSIDERATIONS

- Items should be braced to structural elements with sufficient capacity to resist the imposed loads. Do not brace to other equipment, ducts, or piping. Flexible connections should be provided for fuel lines and piping. Equipment may be suspended either with or without vibration isolation.
- Refer to FEMA 412 *Installing Seismic Restraints for Mechanical Equipment* (2002) and FEMA 414 *Installing Seismic Restraints for Duct and Pipe* (2004) for additional information and details.
- Several engineered seismic bracing systems are available for suspended equipment and can be customized for most applications. Other options may be found on the internet.

Mitigation Examples

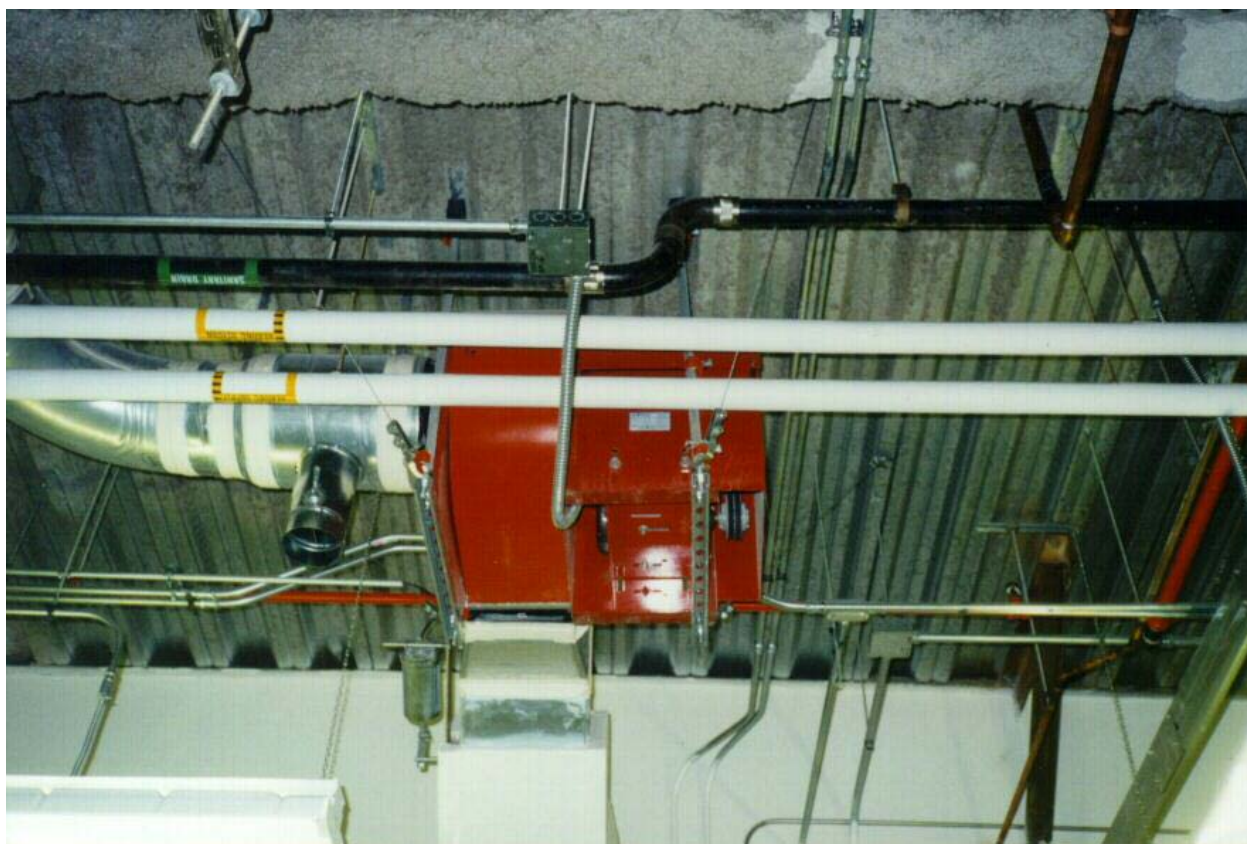


Figure 6.4.1.5-4 Suspended equipment with cable braces (Photo courtesy of Mason Industries).

Mitigation Details

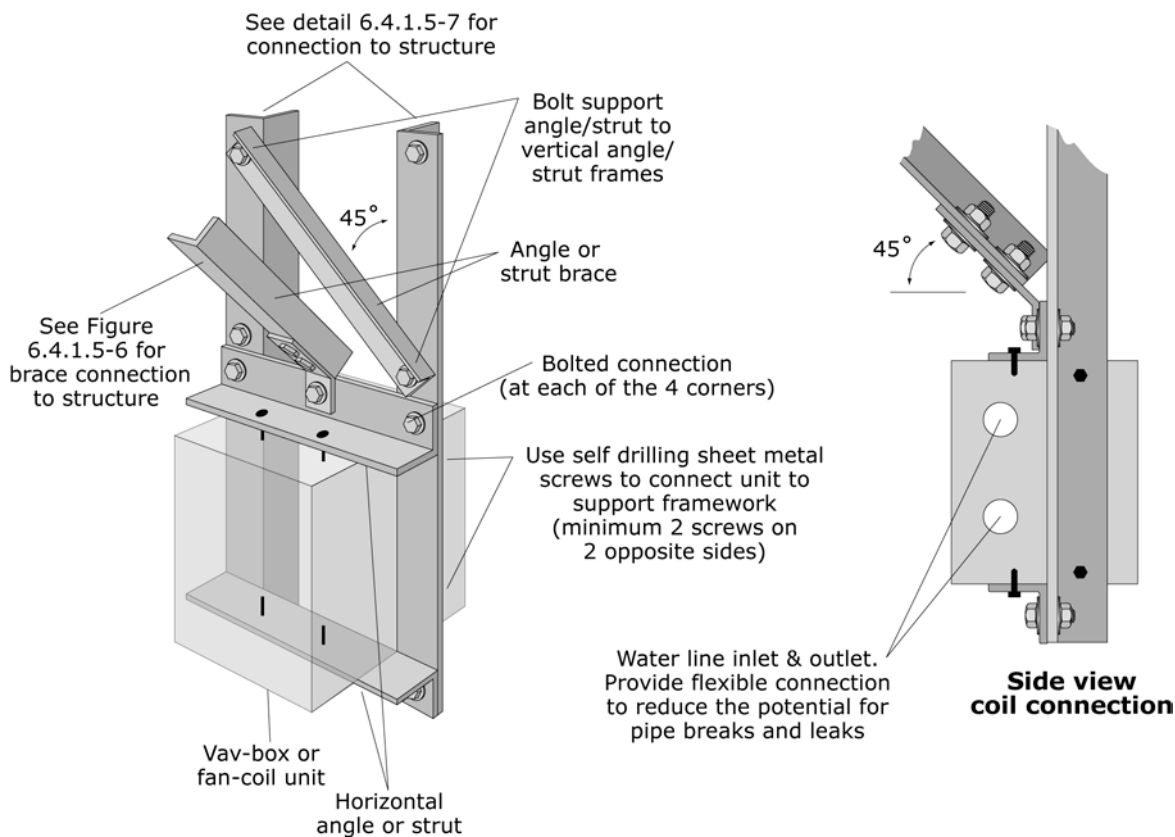


Figure 6.4.1.5-5 HVAC equipment suspended in-line with ductwork (ER).

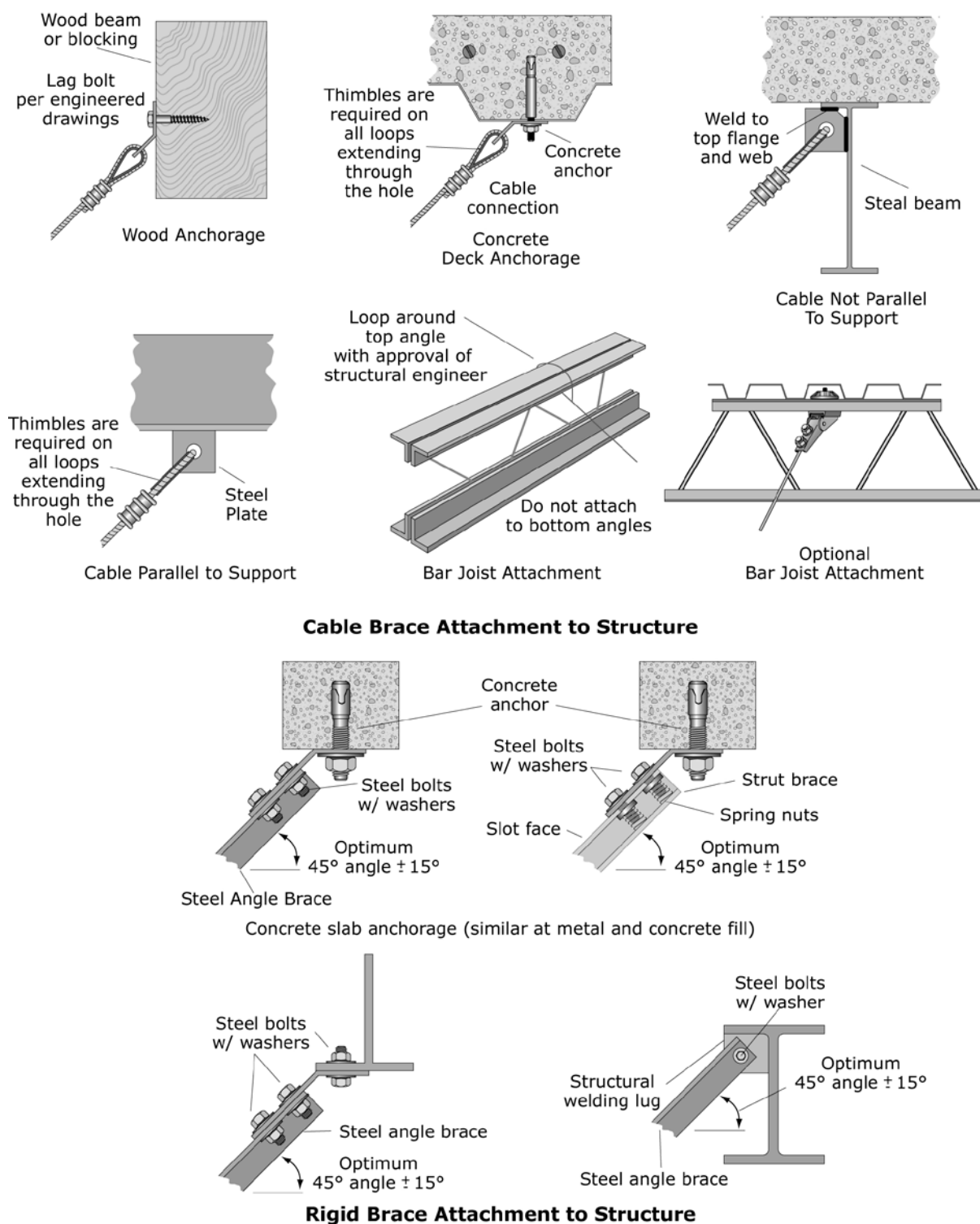


Figure 6.4.1.5-6 Cable and rigid brace attachments to structure (ER).

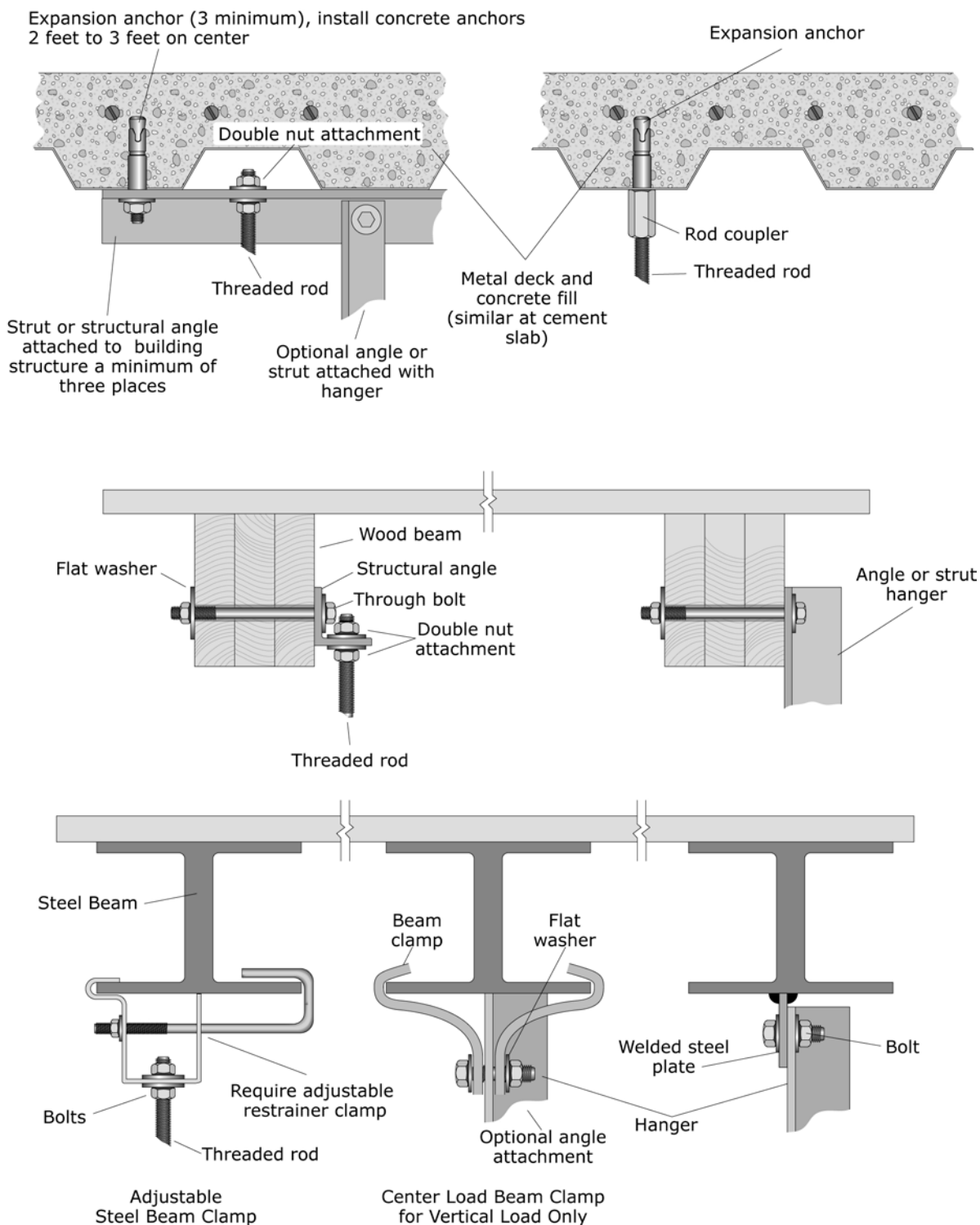


Figure 6.4.1.5-7 Hanger attachment details (ER).

6.4 MECHANICAL, ELECTRICAL, AND PLUMBING COMPONENTS

6.4.1 MECHANICAL EQUIPMENT

6.4.1.6 SUSPENDED EQUIPMENT

This category covers any type of suspended equipment items other than HVAC equipment suspended in-line with ductwork, such as unit gas heaters. Current codes require anchorage for items weighing over 20 pounds that are mounted more than 4 feet above the floor.

TYPICAL CAUSES OF DAMAGE

- Poorly supported suspended items may lose support and fall.
- Suspended items can swing and impact building elements or other equipment.
- Internal components may be damaged by shaking or impact.
- Connections of fuel lines or other connected piping may be damaged.
- Equipment may cease to function due to misalignment or internal damage.

Damage Examples

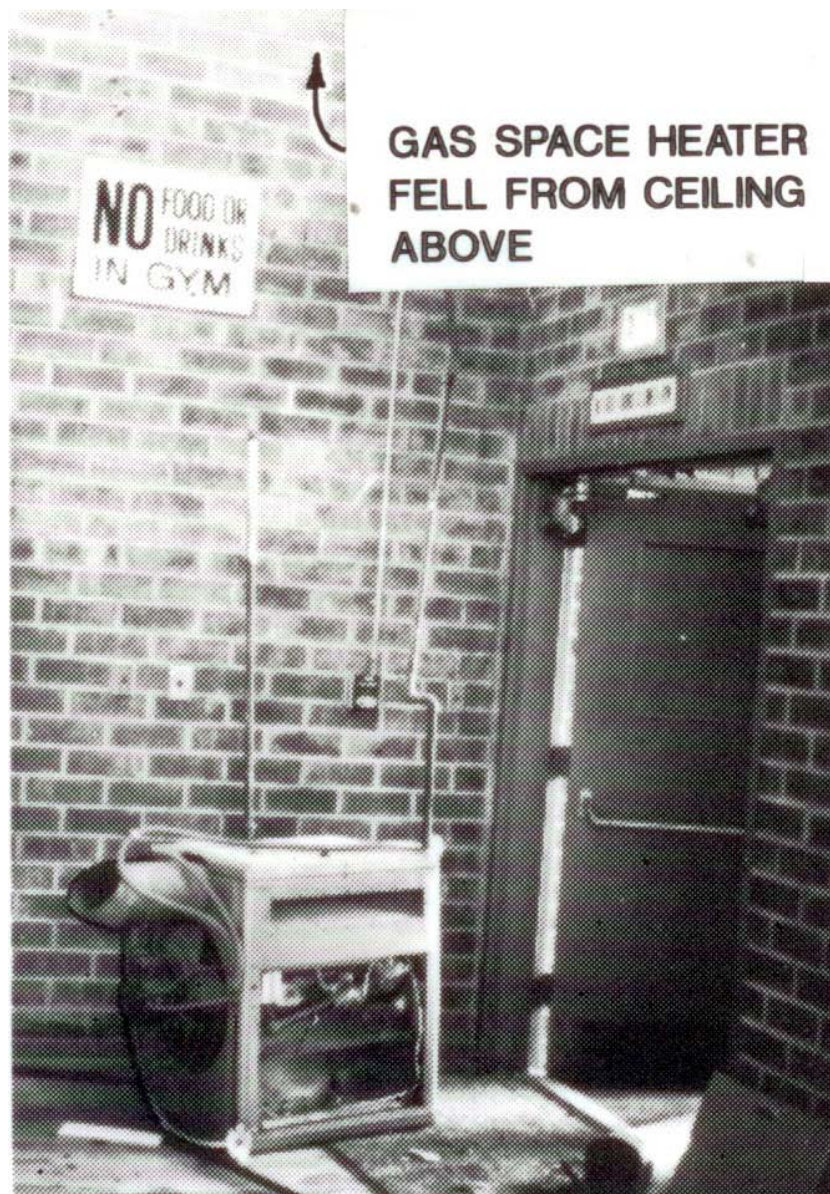


Figure 6.4.1.6-1 Gas space heater fell from ceiling above in the 1971 magnitude-6.6 San Fernando Earthquake (Photo courtesy of C. Wilton, Scientific Service, Inc.).

SEISMIC MITIGATION CONSIDERATIONS

- Detail shown provides rigid attachment for small suspended equipment weighing less than 150 pounds. Two or more double angle assemblies could be used for larger items. If the equipment is suspended with rigid, unbraced hangers, the details shown may be adapted to provide diagonal bracing.
- Provide flexible connections for fuel lines.
- Refer to Section 6.4.1.5 for details for suspended HVAC items; these details can be adapted for multiple suspended items. See also FEMA 412 *Installing Seismic Restraints for Mechanical Equipment* (2002) and FEMA 414 *Installing Seismic Restraints for Duct and Pipe* (2004) for additional information and details.
- Several engineered seismic bracing systems are available for suspended equipment and can be customized for most applications, more options may be found on the internet.

Mitigation Details

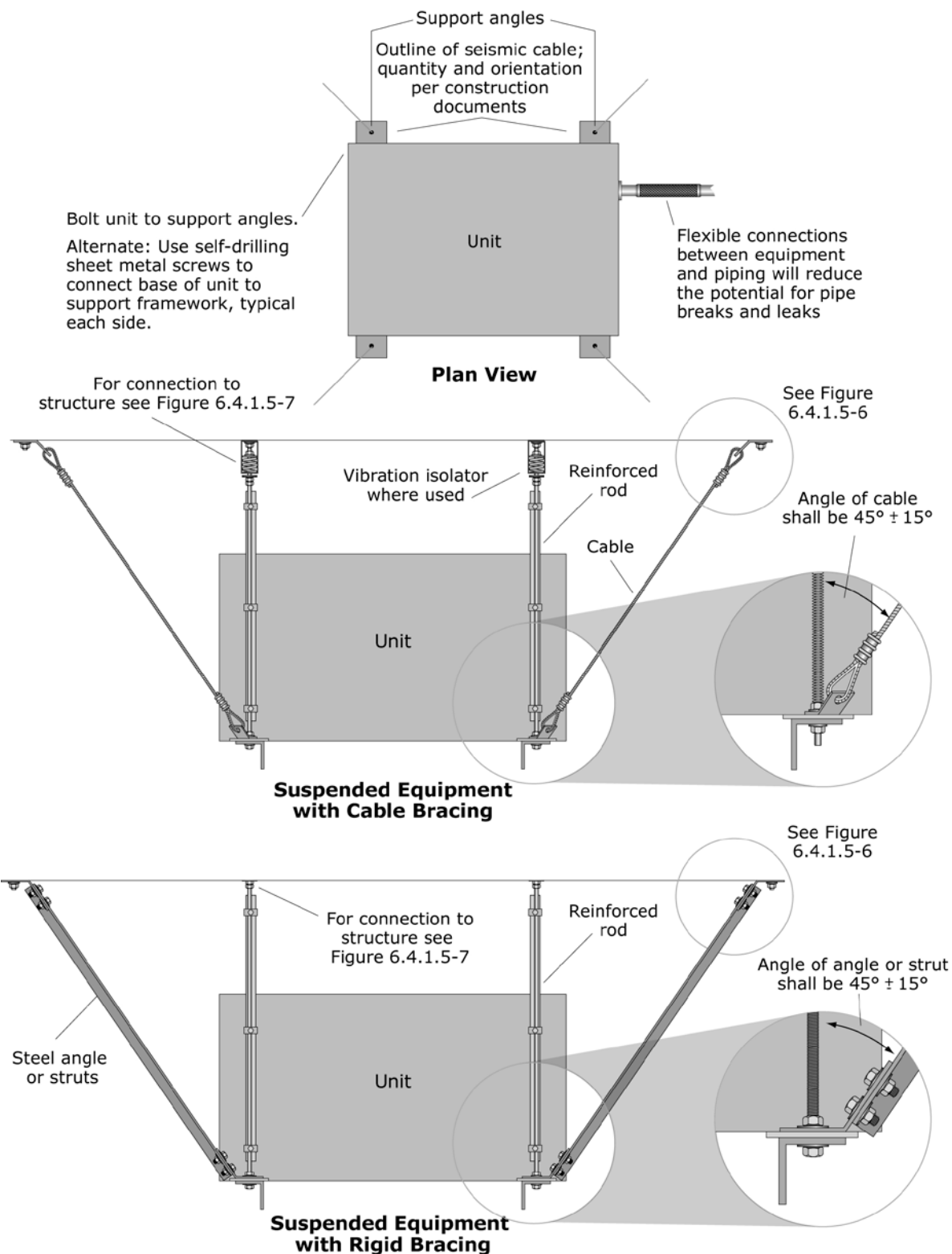


Figure 6.4.1.6-2 Suspended equipment (ER).

6.4 MECHANICAL, ELECTRICAL, AND PLUMBING COMPONENTS

6.4.2 STORAGE TANKS AND WATER HEATERS

6.4.2.1 STRUCTURALLY SUPPORTED TANKS AND VESSELS

This category covers any type of tank or vessel supported on legs or a structural frame and may be either vertical or horizontal. Tanks may be made of steel, stainless steel, polyethylene, polypropylene, fiberglass reinforced plastic (FRP), or concrete.

TYPICAL CAUSES OF DAMAGE

- If the tank is not anchored to the structural supports or the structural supports are not properly braced and anchored, the tanks may slide or fall. Poorly anchored tanks may damage the supports or damage the tank wall.
- Connections of supply lines or fuel lines may be damaged; contents may slosh or spill.

Damage Examples



Figure 6.4.2.1-1 Tank shifted off support curb, Granada Hills Hospital in the 1994 magnitude-6.7 Northridge Earthquake (Photo courtesy of OSHPD).



Figure 6.4.2.1-2 A vertical tank at hospital overturned due to inadequate anchorage in the 1994 Northridge Earthquake (Photo courtesy of OSHPD).



Figure 6.4.2.1-3 Horizontal tank strapped to structural support frame on hospital roof; one strap failed and tank slid six inches in the 1994 Northridge Earthquake (Photo courtesy of OSHPD).



Figure 6.4.2.1-4

Wineries suffered extensive damage in the 2010 magnitude-8.8 Chile Earthquake with many barrels of wine spilled. This winery had damage to anchored tanks; tank anchorage failed, legs buckled, welds tore, anchor bolts pulled up, etc. The tank legs all have leveling bolts at the bottom, creating a weak zone between the bottom of the leg and the anchor plate. Similar unanchored tanks in this facility shifted position but were undamaged (Photos courtesy of Eduardo Fierro, BFP Engineers).

SEISMIC MITIGATION CONSIDERATIONS

- Tanks must have adequate vertical and horizontal support. Provide anchorage and bracing for tank legs or support structure; provide positive attachment from tank to support structure. Provide concrete pad large enough to prevent tank from overturning.
- Provide flexible connections for fuel lines and piping.
- The details shown are for rigid connections; see also FEMA 412 *Installing Seismic Restraints for Mechanical Equipment* (2002) for attachment details.
- For some installations where tanks have a low aspect ratio (i.e., the tank is relatively wide compared to the height) and are unlikely to overturn, it may be preferable to allow the tank to slide rather than providing rigid anchorage. As shown in the photos in Figure 6.4.2.1–4 taken at a winery, many stainless steel tanks on legs with base anchorage were damaged while nearby unanchored tanks shifted slightly but were undamaged. Flexible connections designed to accommodate sliding would be required for tanks left free at the base.

Mitigation Examples



Figure 6.4.2.1-5 Braces added to four sides of tank support structure (Photo courtesy of Eduardo Fierro, BFP Engineers).



Figure 6.4.2.1-6 Gusset plates and cross bracing added at base of vertical tank on four legs following the 2001 magnitude-8.4 Peru Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers).

Mitigation Details

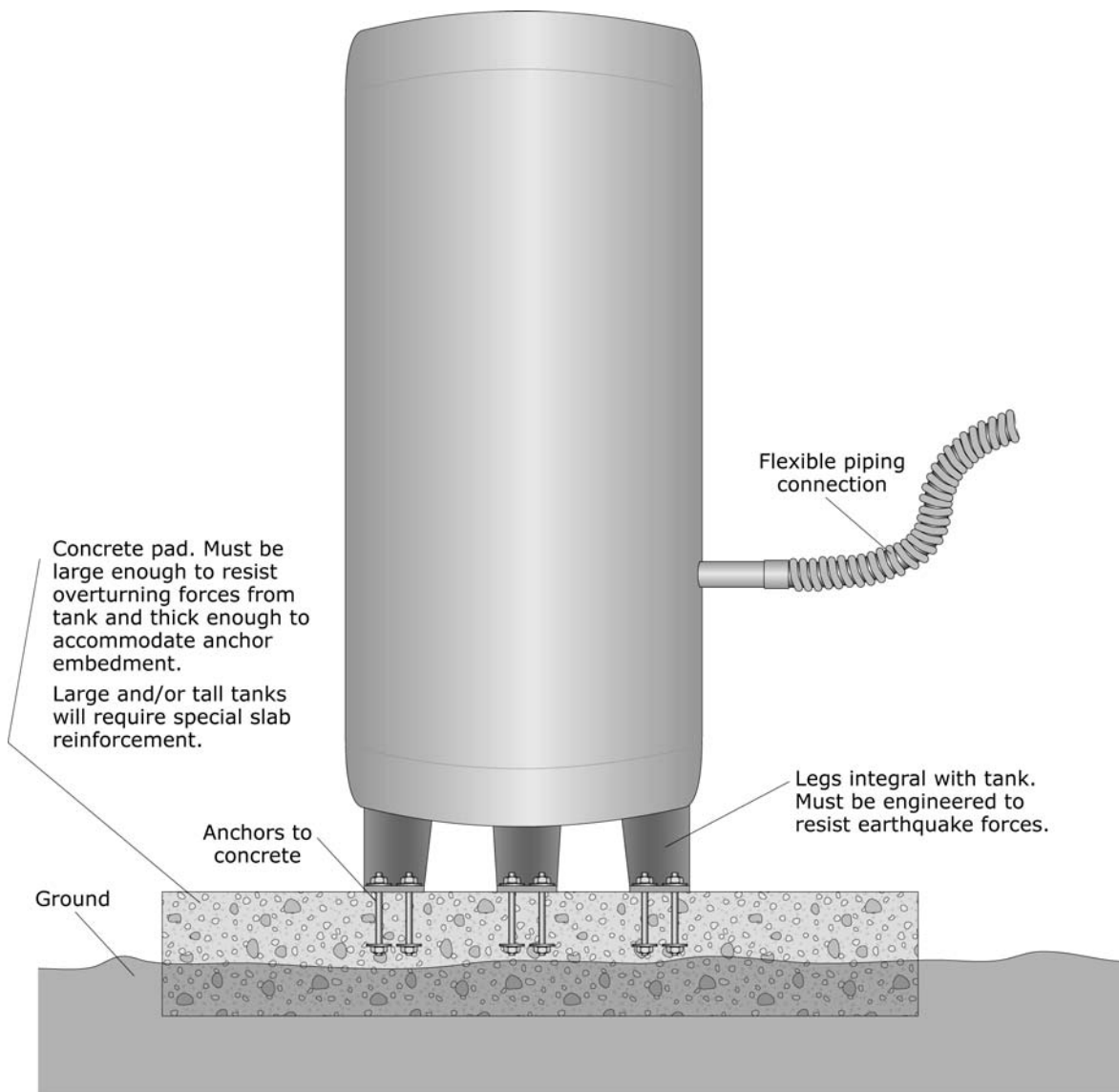


Figure 6.4.2.1-7 Vertical tank on legs (ER).

6.4 MECHANICAL, ELECTRICAL, AND PLUMBING COMPONENTS

6.4.2 STORAGE TANKS AND WATER HEATERS

6.4.2.2 FLAT BOTTOM TANKS AND VESSELS

This category covers any type of flat bottom tank or vessel resting on a concrete pad at the base. These tanks may be made of steel, stainless steel, polyethylene, polypropylene, fiberglass reinforced plastic (FRP), or concrete.

TYPICAL CAUSES OF DAMAGE

- Unanchored tanks may slide or overturn; poorly anchored tanks may damage the hold down, damage the tank wall, and potentially slide or overturn.
- Connections of supply lines or fuel lines may be damaged; contents may slosh or spill.

Damage Examples



Figure 6.4.2.2-1 Damage to ductile connection at base of a 5000 cubic meter diesel fuel tank in the 2001 magnitude-8.4 Peru Earthquake. All eight connections were damaged; damage included bolt elongation, deformation of tank wall, and cracked concrete pad (Photo courtesy of Eduardo Fierro, BFP Engineers).



Figure 6.4.2.2-2 Tank with “elephant’s foot” buckle at the base in the 1964 magnitude-9.2 Anchorage, Alaska earthquake (Photo courtesy of PEER, Steinbrugge Collection, No. S2508)



Figure 6.4.2.2-3 Tank with “elephant’s foot” and “elephant knee” in Port-au-Prince in the 2010 magnitude-7 Haiti Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers).



Figure 6.4.2.2-4 Anchored tank damaged at base when anchorage failed; tank slid and ruptured attached piping in 2010 magnitude-8.8 Chile Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers).

SEISMIC MITIGATION CONSIDERATIONS

- Provide adequate connections around the base of the tank. Do not weld to tanks with flammable contents.
- Provide flexible connections for fuel lines and piping.
- The detail shown is for a rigid connection; larger tanks require ductile details such as those shown in Figure 6.4.2.2-1.

Mitigation Examples

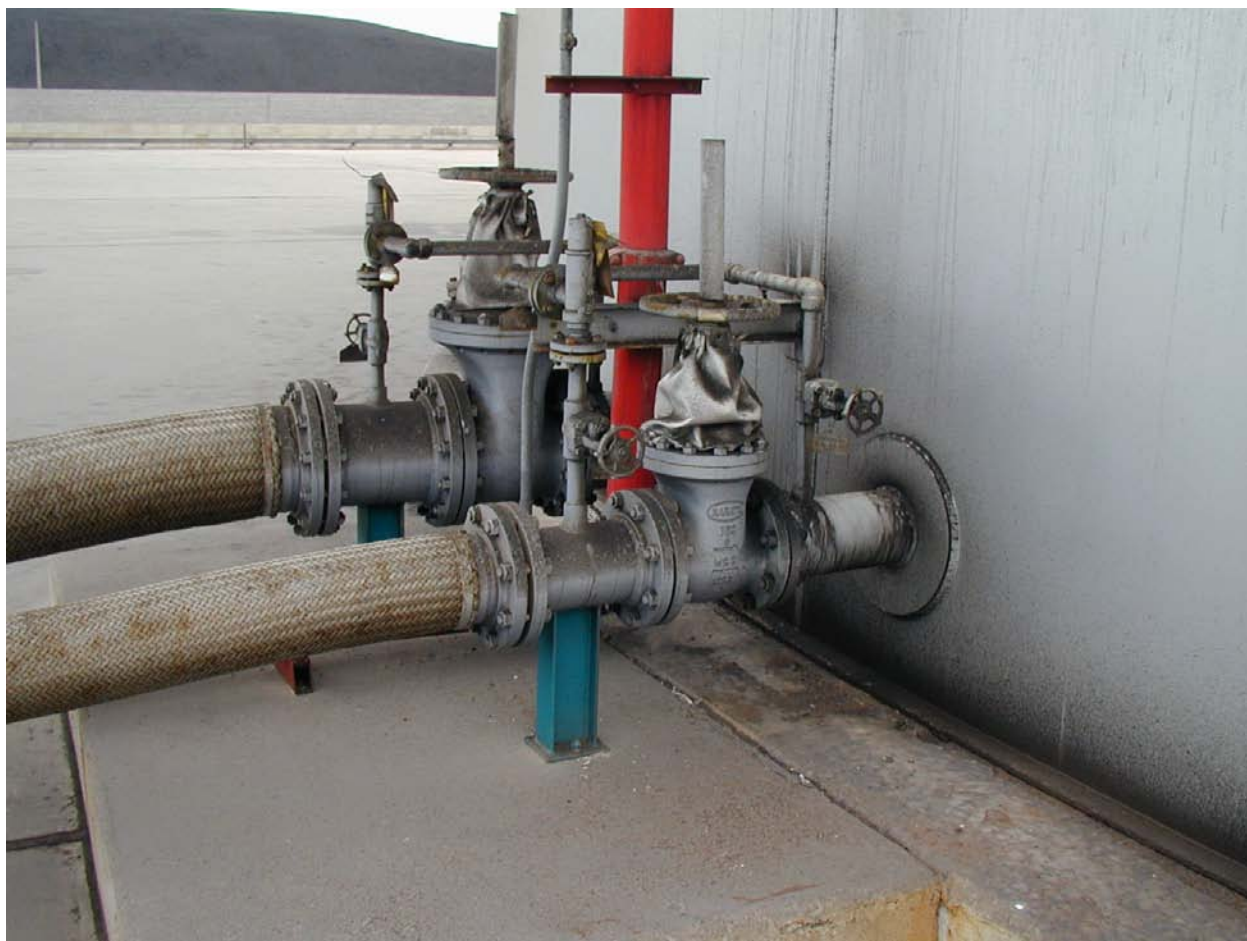


Figure 6.4.2.2-5 Flexible connections prevented piping damage in 2001 Peru Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers).



Figure 6.4.2.2-6 Anchors at base of fiberglass reinforced plastic tank (Photo courtesy of Jeffrey Soulages, Intel).



Figure 6.4.2.2-7 Examples of rigid base anchorage for small circular tanks (Photos courtesy of Maryann Phipps, Estructure).

Mitigation Details

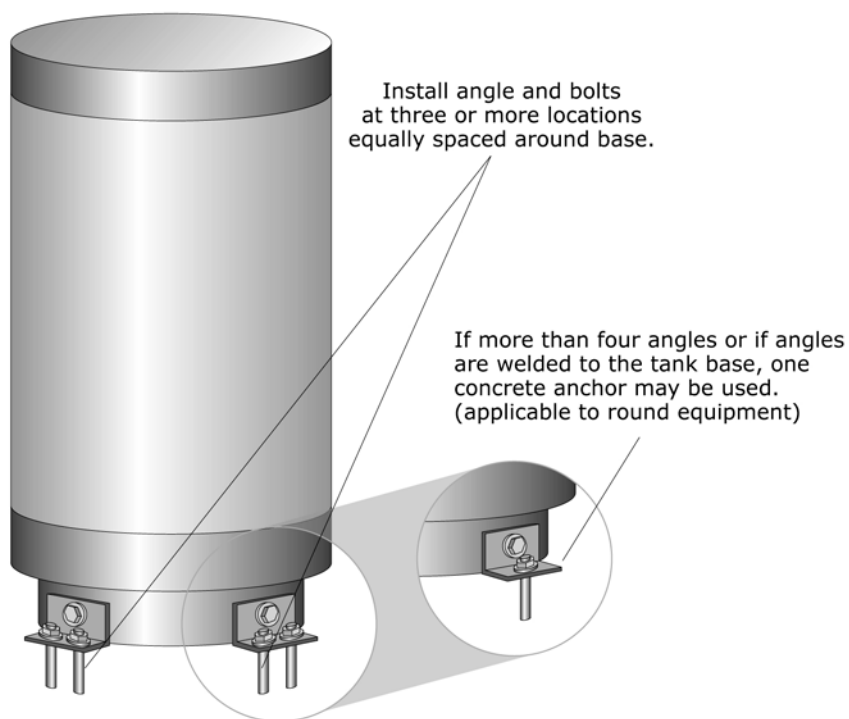


Figure 6.4.2.2-8 Flat bottom tank (ER).

6.4 MECHANICAL, ELECTRICAL, AND PLUMBING COMPONENTS

6.4.2 STORAGE TANKS AND WATER HEATERS

6.4.2.3 COMPRESSED GAS CYLINDERS

This category includes single or multiple gas cylinders. These may be attached to piping, anchored to carts for mobility, or stored for future use.

TYPICAL CAUSES OF DAMAGE

- Unanchored tanks may slide, overturn, and roll; connected piping may be damaged.
- Contents may be flammable or hazardous; leaking cylinders may be dangerous.
- Tank installations equipped with chains or straps are still susceptible to damage unless the chains or straps are properly secured around the tanks.

Damage Examples



Figure 6.4.2.3-1 Unanchored tanks inside fenced enclosure in the 1994 magnitude-6.7 Northridge Earthquake (Photo courtesy of OSHPD).

SEISMIC MITIGATION CONSIDERATIONS

- Wall restraint detail shown at top of Figure 6.4.2.3-8 is a non-engineered detail for tank storage; this detail does not provide sufficient restraint for tanks attached to piping.
- Engineered details with additional restraints are required for tanks attached to piping; see corral detail at bottom of Figure 6.4.2.3-7 or scheme shown in Figures 6.4.2.3-2 and 6.4.2.3-3.

Mitigation Examples



Figure 6.4.2.3-2 Gas cylinder anchorage with attached gas lines undamaged in the 2001 magnitude-8.4 Peru Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers).



Figure 6.4.2.3-3 Detail of undamaged gas cylinder installation (Photo courtesy of Eduardo Fierro, BFP Engineers).



Figure 6.4.2.3-4 Wall-mounted cylinder restraints upgraded with stiffener plates following the 2001 Peru Earthquake(Photo courtesy of Eduardo Fierro, BFP Engineers).



Figure 6.4.2.3-5 Steel tube supports for mobile gas cylinder carts (Photo courtesy of Eduardo Fierro, BFP Engineers).

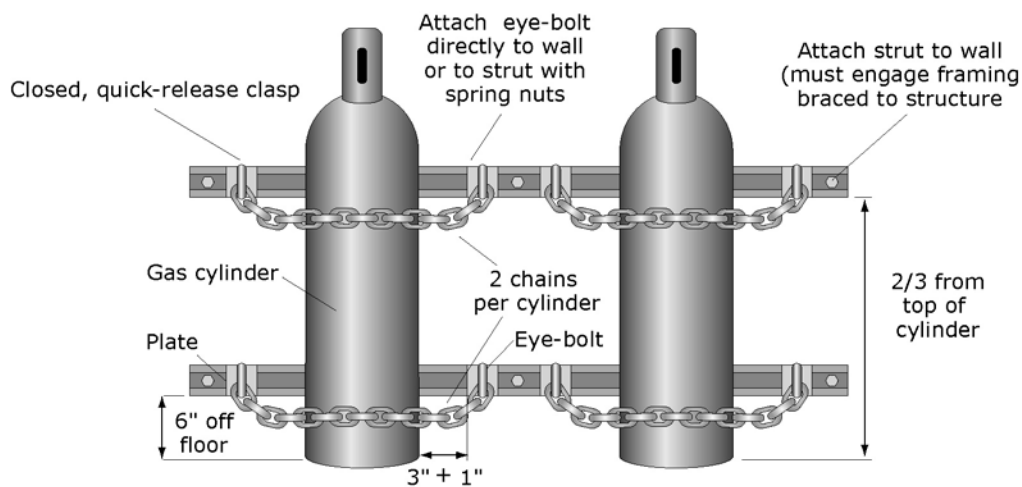


Figure 6.4.2.3-6 Detail of steel tube supports and chains (Photo courtesy of Eduardo Fierro, BFP Engineers).

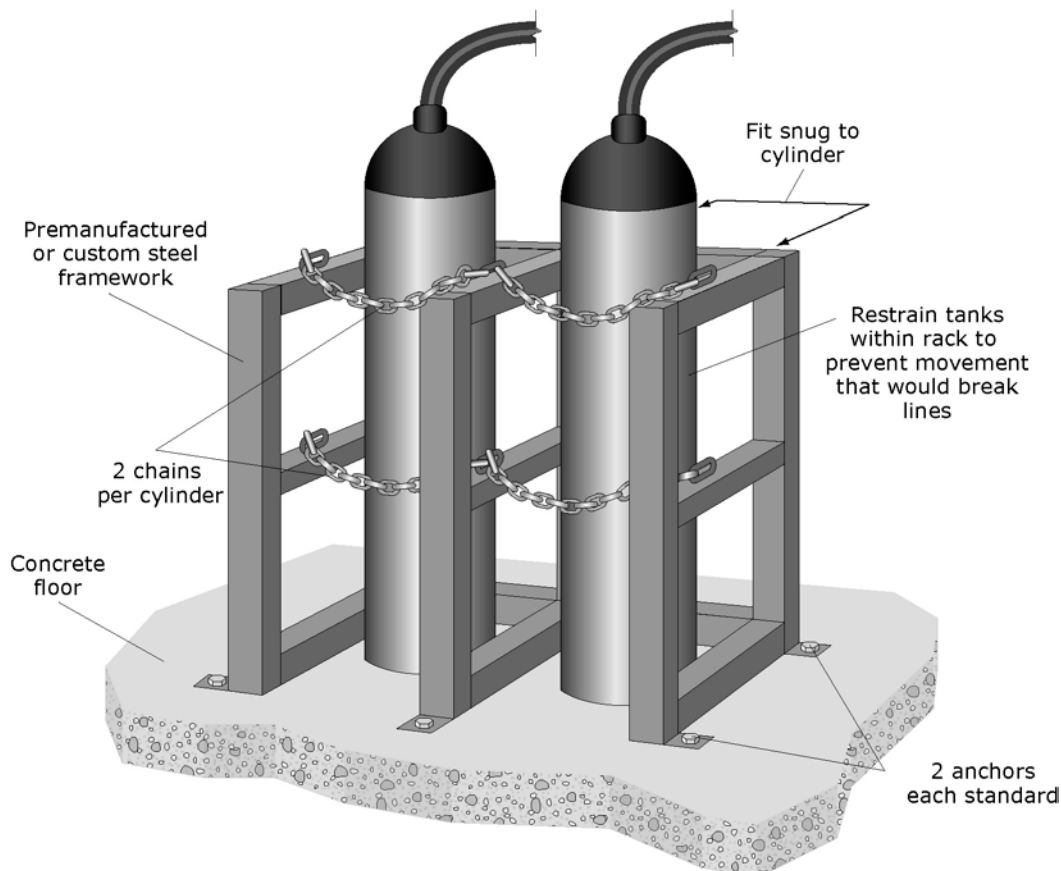


Figure 6.4.2.3-7 Detail of enclosures for airgas tanks in a hospital; chains attached with quick release hooks (Photo courtesy of Maryann Phipps, Estructure).

Mitigation Details



Restraint for Gas Cylinder Against Wall



Restraint for Freestanding Gas Cylinders

Figure 6.4.2.3–8 Compressed gas cylinders (ER).

6.4 MECHANICAL, ELECTRICAL, AND PLUMBING COMPONENTS

6.4.2 STORAGE TANKS AND WATER HEATERS

6.4.2.4 WATER HEATERS

This category includes residential or small commercial water heaters. Most water heaters rest on the floor although smaller units may be wall- or shelf-mounted. Tankless water heaters are often wall-mounted.

TYPICAL CAUSES OF DAMAGE

- Unanchored or poorly anchored tanks may slide or overturn.
- Even if the restraint is strong enough to prevent complete overturning, if it is not rigid enough, the connections to gas and water lines may be damaged by tank movement and lead to fire or to water leakage

Damage Examples



Figure 6.4.2.4-1 Unanchored water heaters overturned (Photo courtesy of Mason Industries).



Figure 6.4.2.4-2 Continuing water damage at the Talca Hospital in the 2010 magnitude-8.8 Chile Earthquake; water leaking from tank at right. This building was closed due to nonstructural damage, dominated by water damage (Photos courtesy of Bill Holmes, Rutherford & Chekene).

SEISMIC MITIGATION CONSIDERATIONS

- Details shown are for tanks resting on the floor adjacent to a structural wall. Where the water heater is not located adjacent to a wall, it may be necessary to construct a frame around the tank or adjacent to the tank to provide anchorage.
- Flexible connections should be provided for the gas and water lines.

- Provide noncombustible spacers between the tank and wall for older units; newer units often have insulation inside the housing as part of the assembly and do not require the additional spacers.
- Larger tanks may be floor-mounted as shown for flat bottom tanks in Section 6.4.2.2 or as pictured in Figure 6.4.2.4–5
- See also *Guidelines for Earthquake Bracing of Residential Water Heaters* (California Department of General Services, 2005c) online at www.documents.dgs.ca.gov/dsa/pubs/waterheaterbracing_11_30_05.pdf for additional information.

Mitigation Examples



Figure 6.4.2.4-3 Water heater corner installation using thin conduit (EMT) braces (Photo courtesy of California Department of General Services).



Figure 6.4.2.4-4 Corner installation using a commercially available strap; note flex copper tubing for water hook up (Photo courtesy of Cynthia Perry, BFP Engineers).



Figure 6.4.2.4-5 Base-mounted water heater located in a school; equipment supplied with metal base for mounting (Photo courtesy of EQE for the Salt Lake City School District).

Mitigation Details

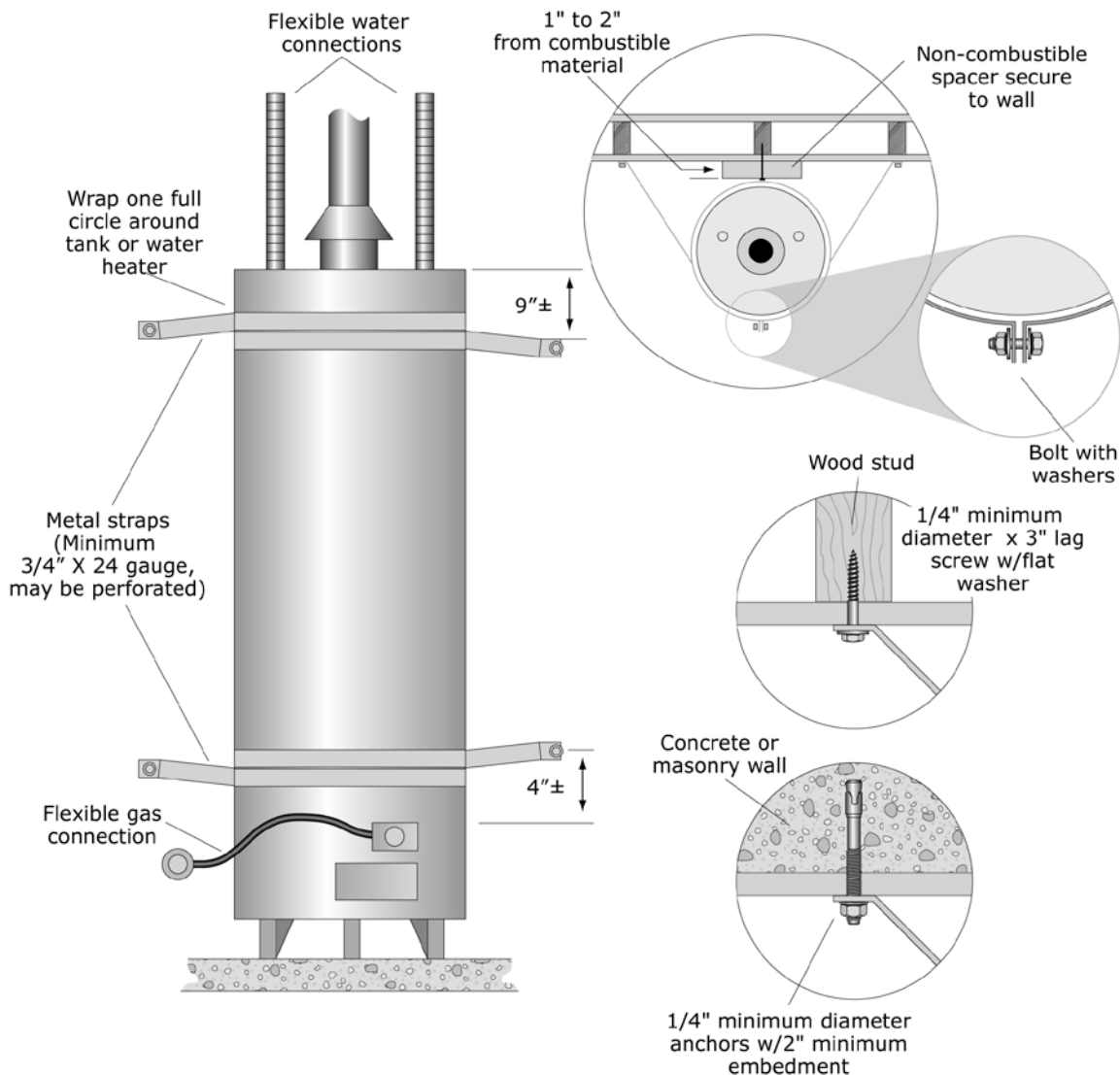


Figure 6.4.2.4-6 Water heater (PR).

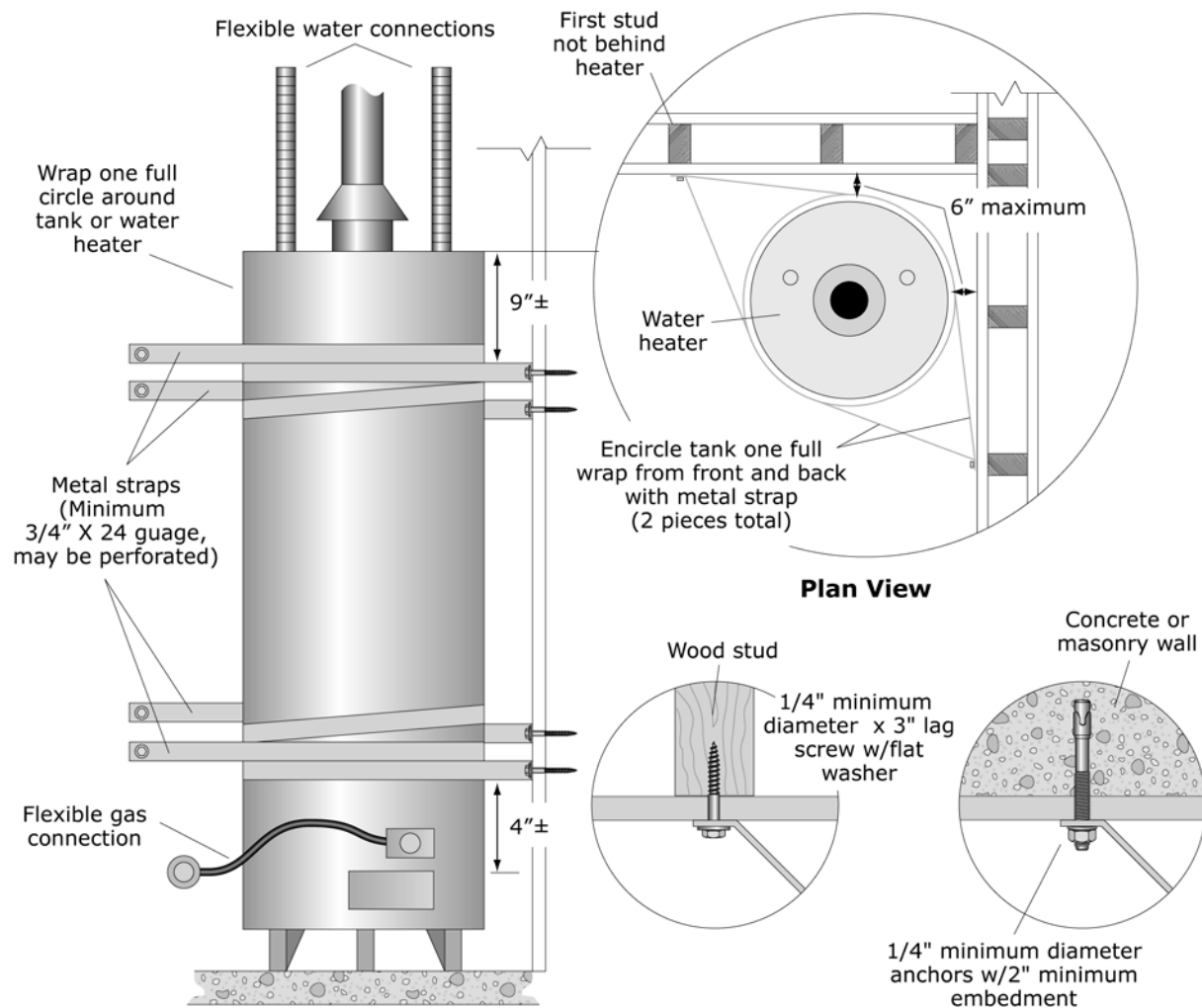


Figure 6.4.2.4-7 Water heater - corner installation (PR).

6.4 MECHANICAL, ELECTRICAL, AND PLUMBING COMPONENTS

6.4.3 PRESSURE PIPING

6.4.3.1 SUSPENDED PRESSURE PIPING

There are many types of piping systems which convey a wide variety of fluids and gases in and around buildings. In this section, pressure piping refers to “all piping (except fire suppression piping) that carries fluids which, in their vapor stage, exhibit a pressure of 15 psi, gauge, or higher.” See Sections 6.4.4 and 6.4.5 for other piping categories. This example addresses seismic restraint details for suspended piping; see Sections 6.4.3.2 through 6.4.3.8 for other types of piping system restraints as shown in Figure 6.4.3.1–10.

TYPICAL CAUSES OF DAMAGE

- Improperly supported pipes can become dislodged and fall.
- Pipes are particularly vulnerable to damage at joints, bends, penetrations through walls or structural members, and connections to equipment.
- Unbraced piping can sway and impact adjacent items.
- Piping may be damaged as a result of differential movement between points of attachment.
- Fluids may leak from damaged joints or broken pipe; property losses and business outages are often attributed to fluid leaks from piping.

Damage Examples

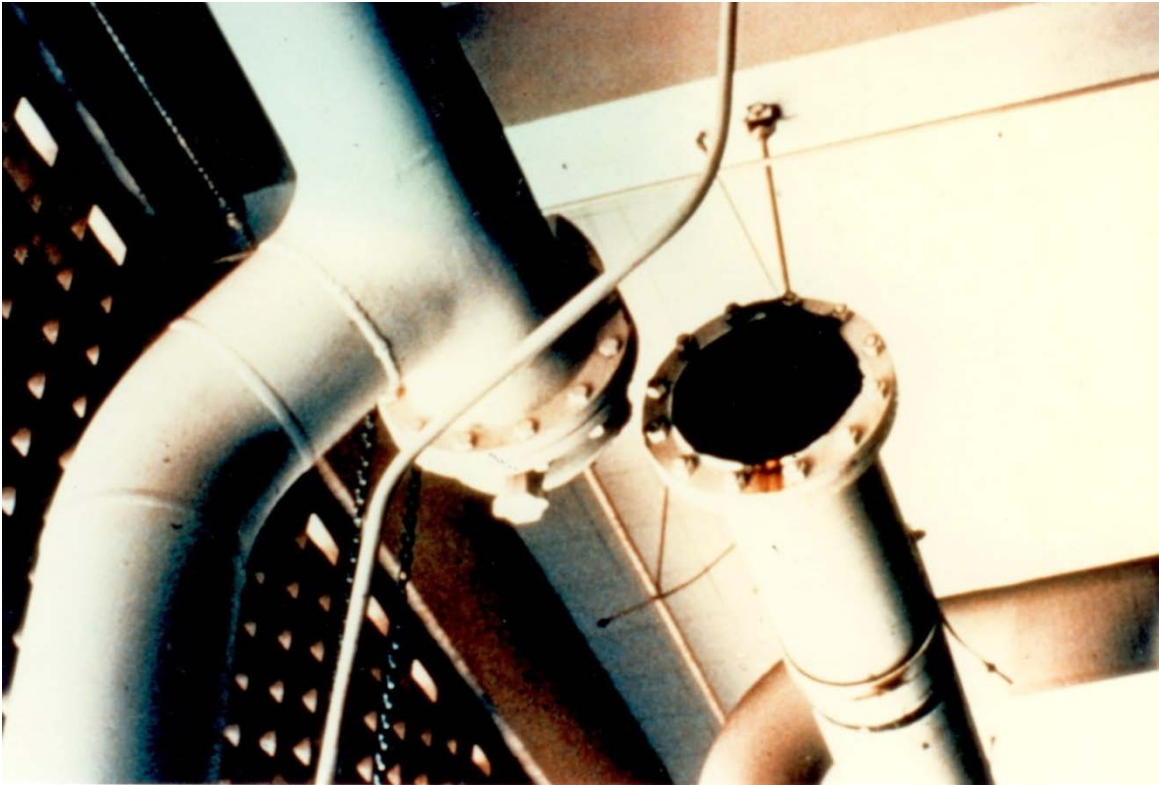


Figure 6.4.3.1-1 Pipe joint failure in the 1971 magnitude-6.6 San Fernando Earthquake (Photo courtesy of John F. Meehan).



Figure 6.4.3.1-2 Leakage caused by pipe damage at joint in the 1994 magnitude-6.7 Northridge Earthquake (Photo courtesy of Degenkolb Engineers).

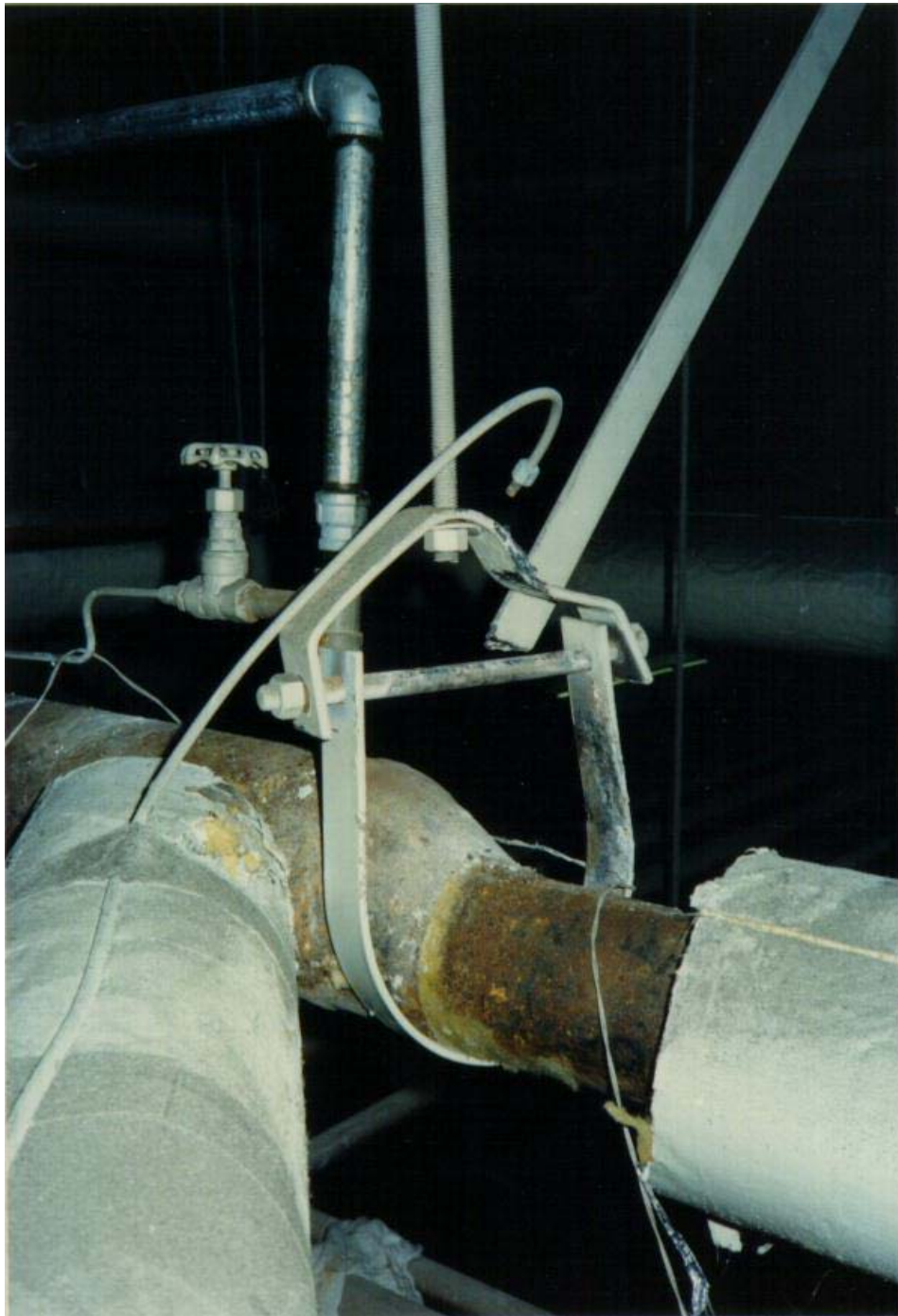


Figure 6.4.3.1-3 Pipe brace failed at connection in 1994 Northridge Earthquake; insulation removed prior to photo (Photo courtesy of Mason Industries).

SEISMIC MITIGATION CONSIDERATIONS

- Details shown are for overhead attachments for suspended piping. Seismic detailing for pipes requires both transverse and longitudinal braces; while these are shown here as separate details, both types of bracing are required. The spacing of pipe bracing is dependent on the level of seismicity, location in a building, size of the pipe, type of pipe, and strength of connections to the structure.
- Pressure piping systems, including their supports, may be designed either using the provisions of ASME B31 *Process Piping* (ASME, 2008) or ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2010). See Section 6.4.4 for issues related to fire protection piping systems.
- ASCE/SEI 7-10 contains a number of exemptions for suspended piping where the hangers are less than 12 inches long or “high-deformability piping” is used and the pipe diameter is small (anywhere from 1- to 3-inch diameter depending on the building location and occupancy). If piping is unbraced, provisions must be made to accommodate anticipated movement (such as by providing flexible connections, as shown in Section 6.4.3.3)
- Many vendors supply specialized hardware used for the seismic anchorage or sway bracing of piping systems. These vendors offer a wide variety of products and services including design, installation and inspection manuals, load tables, load rated hardware, spring loaded hangers, couplers and fittings, pipe dampers, preassembled seismic bracing kits, AUTOCAD details, calculation packages, and technical support.
- Longitudinal pipe bracing requires the use of a pipe clamp, riser clamp, welded lug or device that provides positive attachment to the pipe and will not slip along the length of the pipe. Longitudinal pipe supports should not rely on friction connections such as U-bolts as these do not provide reliable longitudinal restraint during an earthquake and are likely to slip. Some vendors have items with names such as “seismic pipe clamp” or “longitudinal restraint device” that are intended for use with longitudinal restraints.
- Virtual Design and Construction (VDC) and Building Information Models (BIM) involve the development of 3D computer models depicting all the structural and many nonstructural components of buildings. Increasing use of these 3D models that incorporate all the MEP systems will facilitate the design and coordination of these components with the structural system and other nonstructural components. An example of a BIM model with piping and pipe supports is shown in Figure 6.4.3.1-9.
- Piping systems are typically combinations of horizontal and vertical runs of pipe; vertical runs are often called risers. Pipes may be suspended overhead as shown in this

example or floor-mounted, roof-mounted, or wall-mounted. Flexible connections are often required at fixed equipment or where piping crosses an expansion joint or seismic separation. Pipe runs also typically include penetrations through floor slabs, roof slabs, and walls or structural framing. Details for many restraint conditions can be found in FEMA 414 *Installing Seismic Restraints for Duct and Pipe (2004)*. Some of these conditions are shown in Sections 6.4.3.2 through 6.4.3.8 (See Figure 6.4.3.1–11).

Mitigation Examples

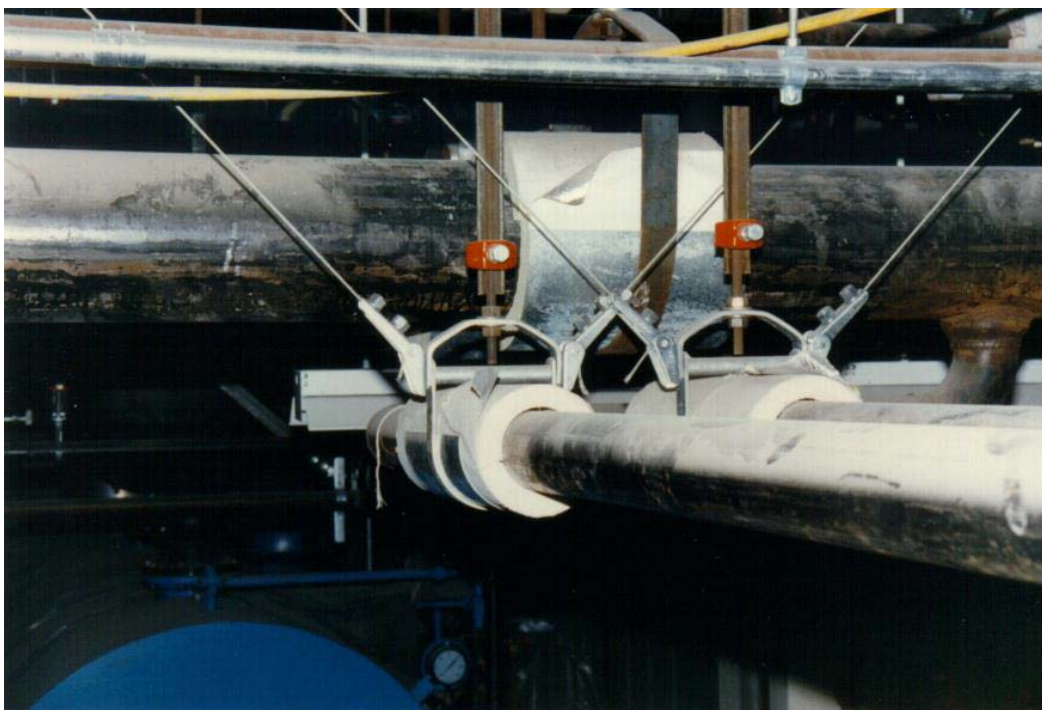


Figure 6.4.3.1-4 Single clevis hanger support with transverse cable bracing at the restraining bolt (Photo courtesy of Mason Industries).

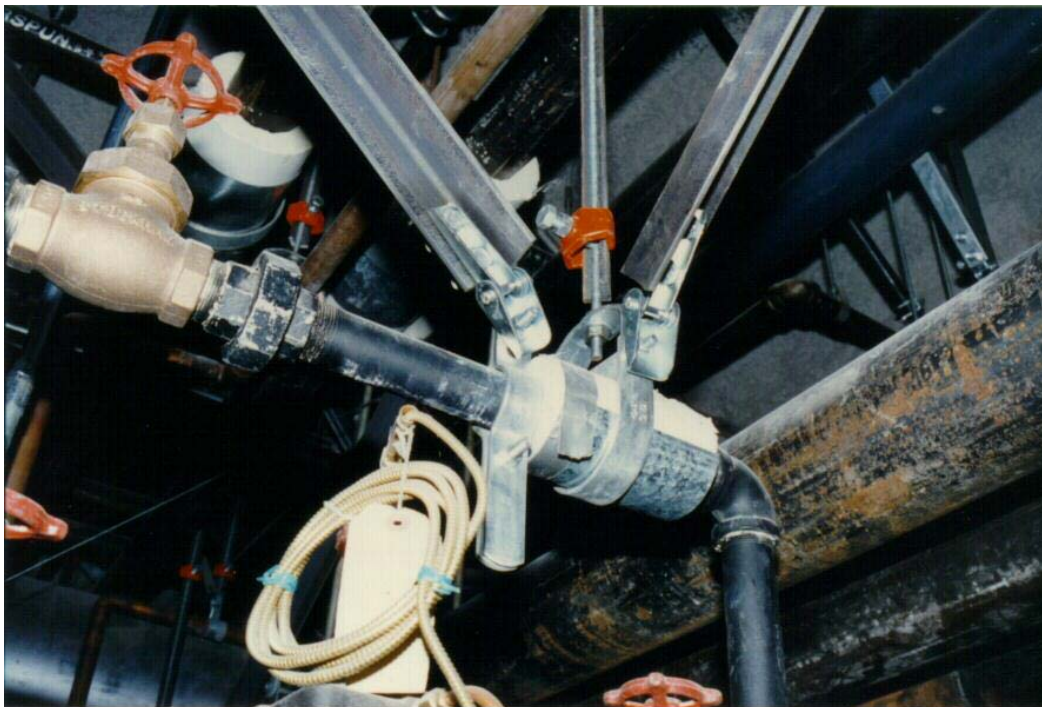


Figure 6.4.3.1-5 Pipe clamp supports with transverse and longitudinal angle braces; note pipe clamp for longitudinal brace in direct contact with pipe (Photo courtesy of Mason Industries).



Figure 6.4.3.1-6 All-directional cable bracing of suspended piping (Photo courtesy of ISAT).



Figure 6.4.3.1-7 Transverse bracing with J-hanger and strut at the restraining bolt. Note that longitudinal brace shown is ineffective because the J-hanger can slip along the length of the pipe; a pipe clamp or equivalent is required for a longitudinal brace (Photo courtesy of Cynthia Perry, BFP Engineers).

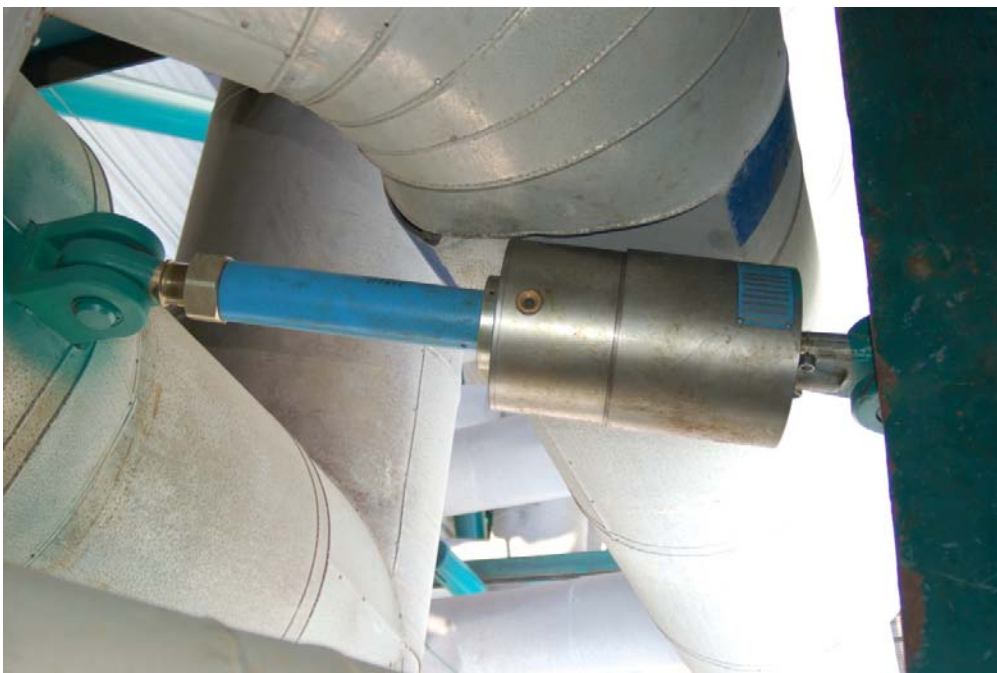


Figure 6.4.3.1-8 Viscous damper used as restraint on large insulated pipe (Photo courtesy of Eduardo Fierro, BFP Engineers).



Figure 6.4.3.1-9 Example of BIM Model (left) compared to installed piping (right) (Photo and image courtesy of ISAT).

Mitigation Details

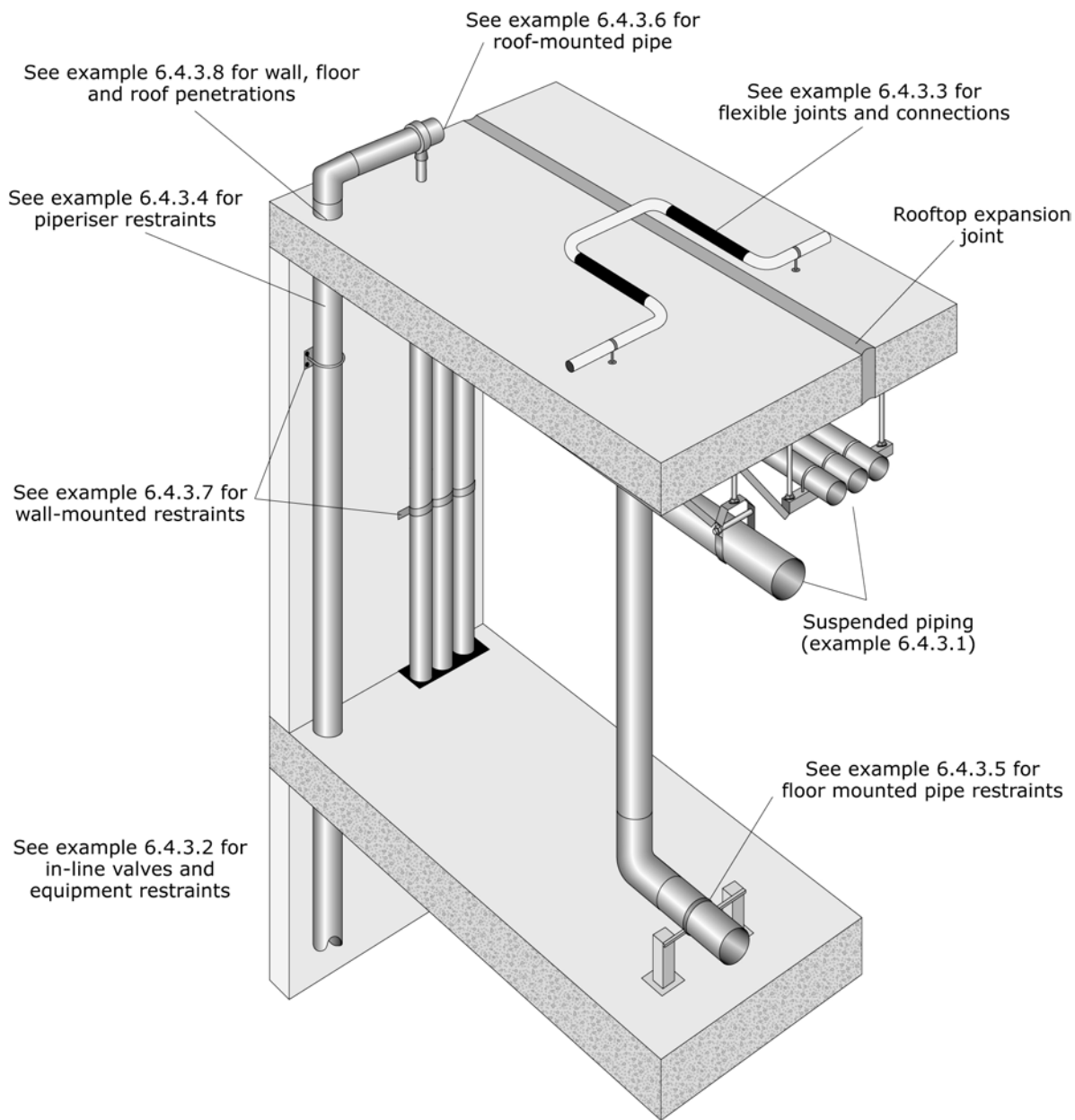


Figure 6.4.3.1-10 Schematic of seismic restraint conditions for piping (ER)

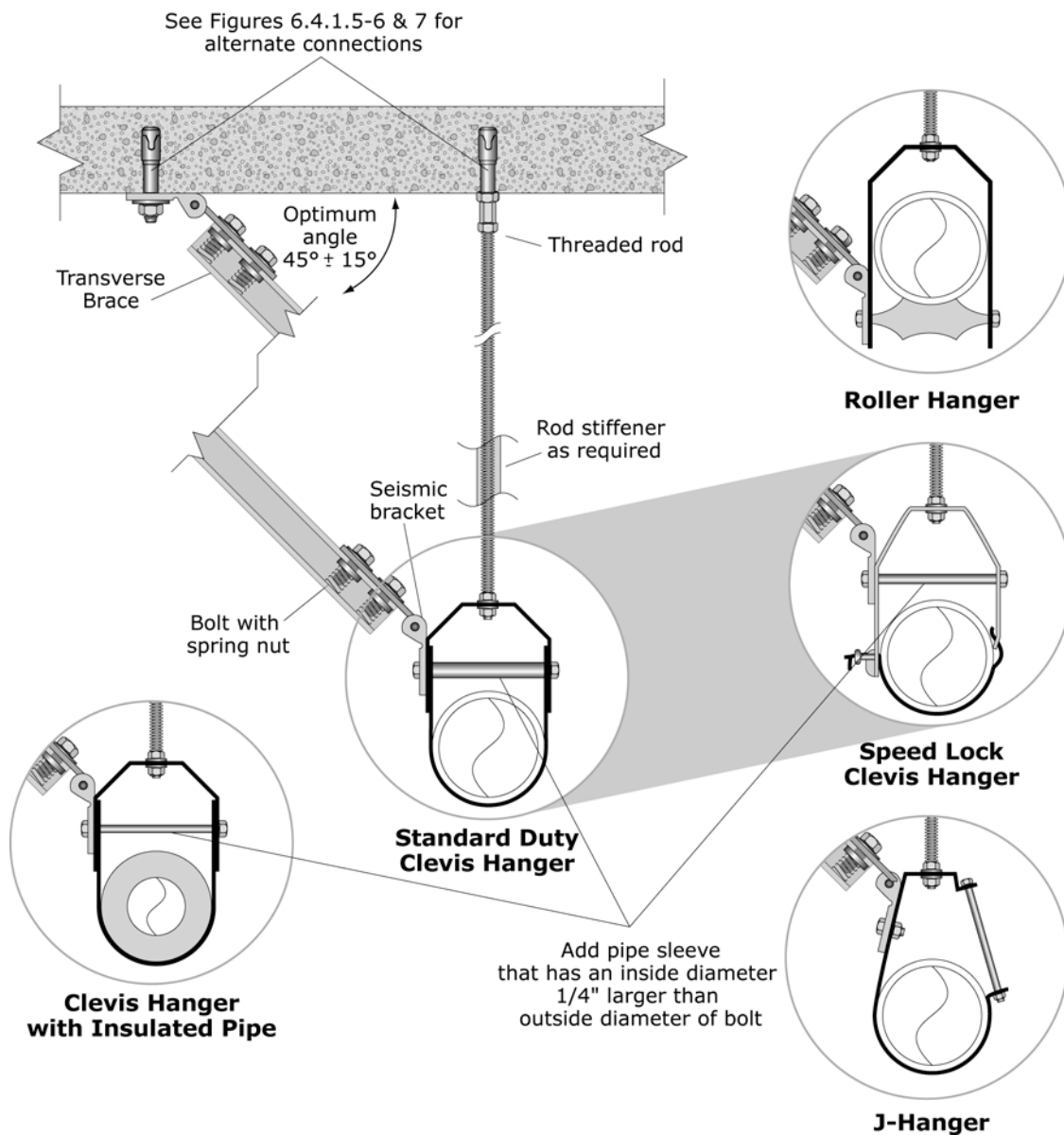


Figure 6.4.3.1-11 Rigid bracing - single pipe transverse (ER).

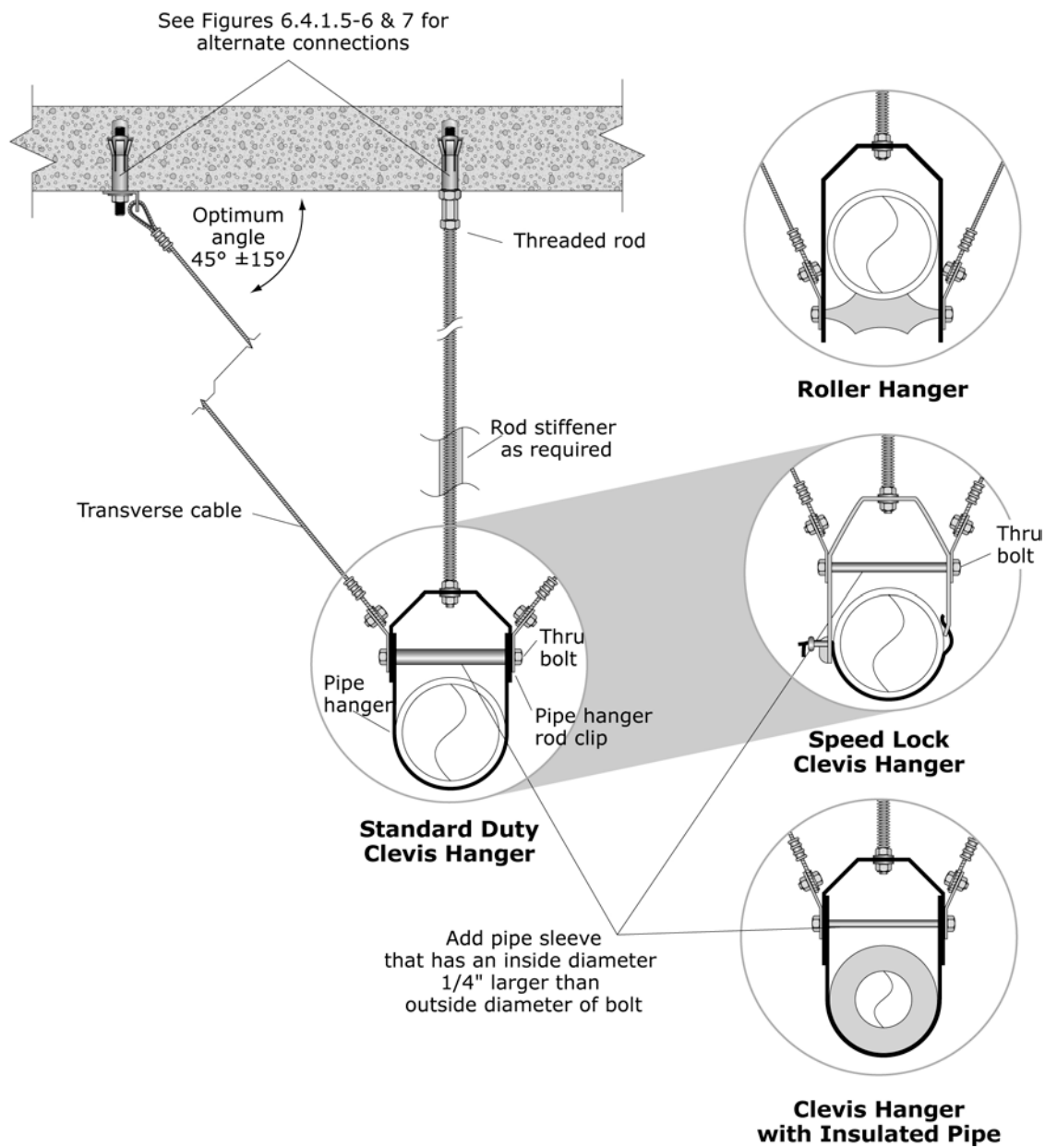


Figure 6.4.3.1-12 Cable bracing - single pipe transverse (ER).

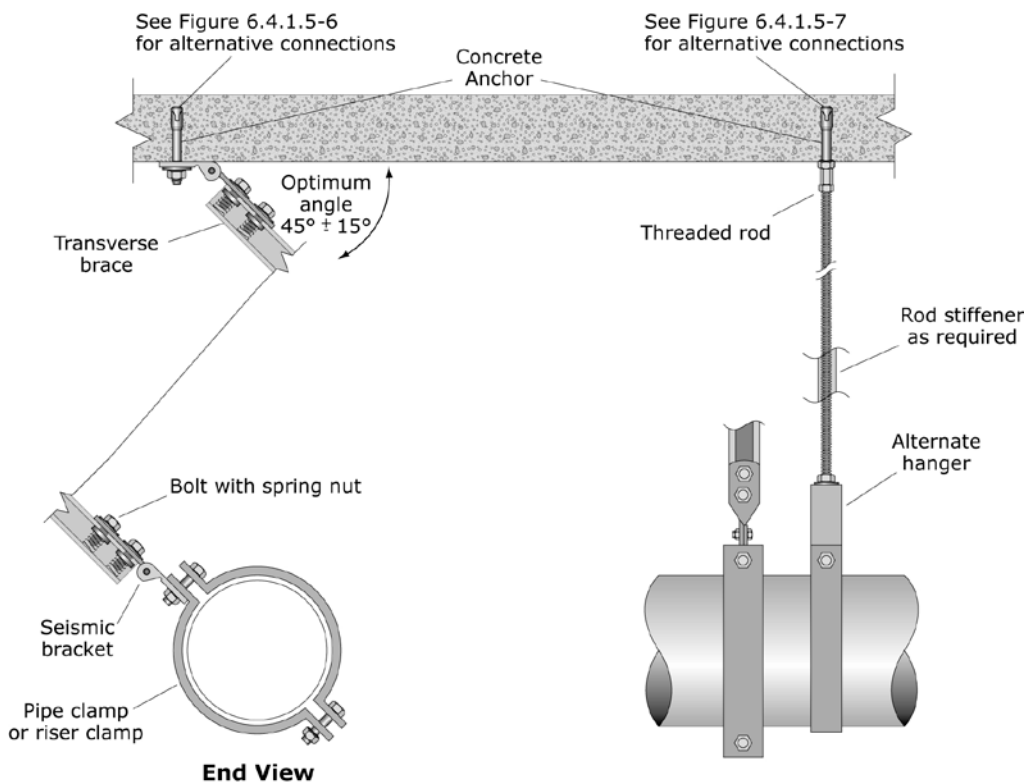


Figure 6.4.3.1-13 Rigid bracing - single pipe alternate transverse (ER).

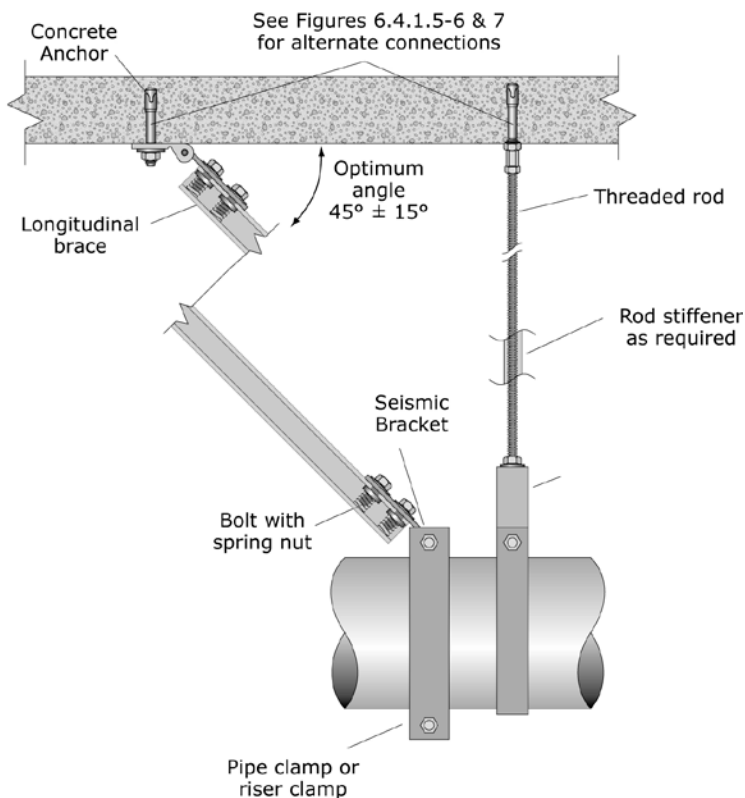


Figure 6.4.3.1-14 Rigid bracing - single pipe longitudinal (ER).

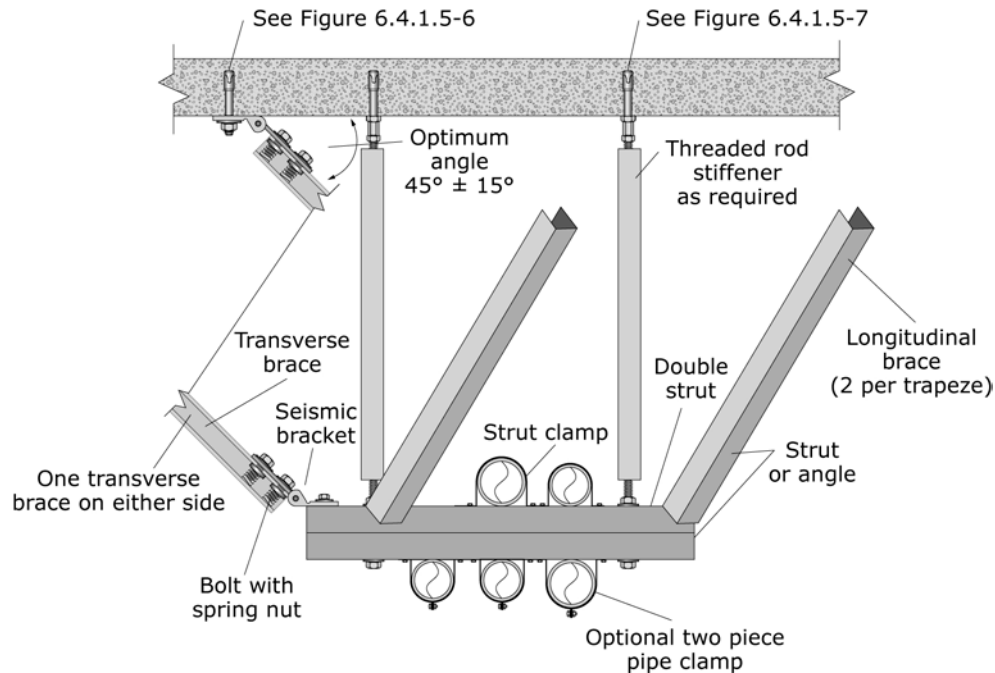


Figure 6.4.3.1-15 Rigid bracing - Trapeze supported piping (ER).

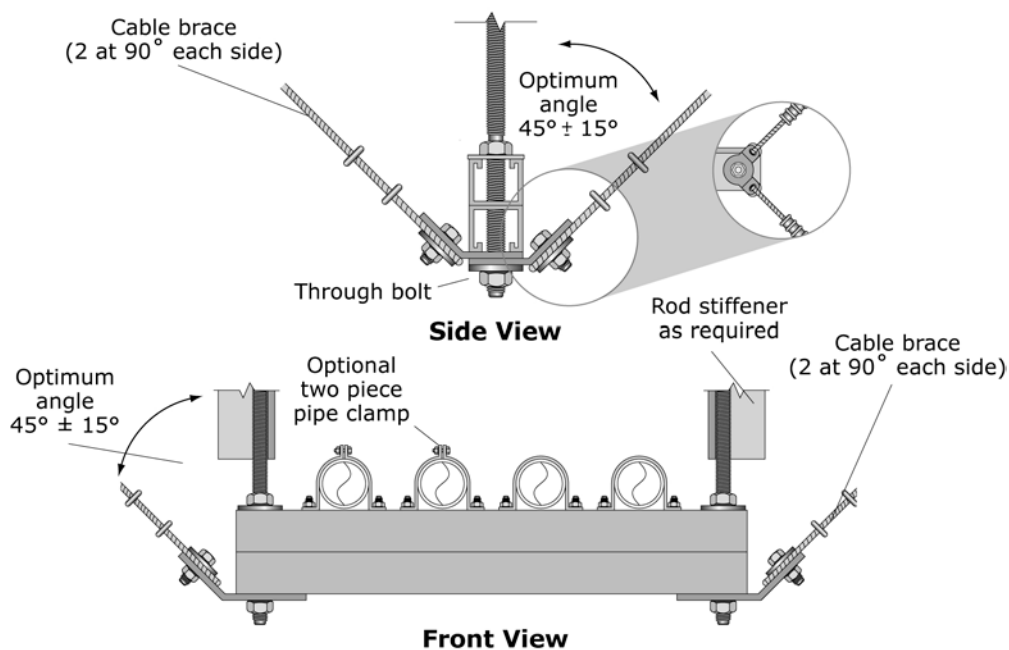


Figure 6.4.3.1-16 Cable bracing - Trapeze supported piping (ER).